MONTHLY NOTICES

OF THE

ROYAL ASTRONOMICAL SOCIETY

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MEETING OF 1945 MAY 11

Professor H. H. Plaskett, President, in the Chair

The election by the Council of the following Fellows was duly confirmed:—

William Parkinson Hirst, B.A., Longwood, Camp Ground Road, Newlands, Cape Province, S. Africa;

Matthew Hall Lambert, 8 Lisle Road, South Shields, Durham; and

Hugh Percival Wilkins, 127 Eversley Avenue, Barnehurst, Kent.

The following candidates were proposed for election as Fellows of the Society, the names of the proposers from personal knowledge being appended:—

Egil Kristoffar Bjørnerūd, Sagatūn, Hamar, Norway (proposed by H. Spencer Jones);

Peter Kerr, M.A., B.Sc., Woodland View, Hooton Road, Hooton, Cheshire (proposed by L. J. Comrie);

Desmond Gerard O'Sullivan, B.Sc., 18 Virginia Gardens, Barkingside, Ilford, Essex (proposed by Violet F. White);

Michael William Ovenden, 22 Coppetts Road, Muswell Hill, London, N. 10 (proposed by F. M. Holborn); and

Thomas Wilson Wormell, Ph.D., Solar Physics Observatory, Cambridge (proposed by H. A. Brück).

In response to a request from the Directors of the Astronomical Society of the Pacific, the Astronomer Royal (with the permission of the President) presented the Catherine Wolf Bruce Medal for the year 1945 to Professor E. A. Milne to whom it had been awarded for his distinguished services to astronomy.

Fifty-four presents were announced as having been received since the last meeting.

ON THE SUN'S GENERAL MAGNETIC FIELD

T. G. Cowling

(Received 1945 July 3)

Summary

The time of electromagnetic decay of the Sun's general magnetic field is shown to be 10^{10} years, suggesting that the field may be a relic from a different primeval state. An alternative hypothesis, ascribing the field to thermal effects due to convection in the rotating Sun, is shown to give a field of the correct sign, but less than 10^{-7} times the observed field; and a modification of the hypothesis, supposing that the field due to thermal currents is magnified by dynamo action, is shown to demand over 10^{18} years for the field to grow to its present size. Other possible explanations of the Sun's field are suggested.

In an Appendix, the effect of the Sun's rotation on turbulence in its interior is briefly considered.

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1. Our knowledge of solar magnetic fields is almost entirely derived from the work of Hale and his collaborators at Mount Wilson. By observations of polarization at the wings of spectral lines, these workers identified a general magnetic field of the Sun, similar in many respects to the Earth's magnetic field.* The field-strength is of order (say) 25 gauss; the axis of the field is inclined to the axis of rotation of the Sun at about 6°, and rotates round it in about $31\frac{1}{2}$ days. Different spectral lines indicate different intensities for the field; weak lines suggest larger fields than strong lines. Since the latter probably originate at greater heights in the Sun's atmosphere than the former, these results were interpreted as implying that the field falls off rapidly with increasing height.

The average observed separation of the Zeeman components is of the same order as the probable error of a single measurement. Because of its smallness, its reality is sometimes doubted. The present author sees no reason to share these doubts. To ensure that personal bias should not colour the results, the original observer measuring the Zeeman displacements was kept in ignorance of the hemisphere and latitude of the observations. Thus if he were prone to imagine a non-existent phenomenon, he would give it sometimes one sign, sometimes the other, and in the aggregate his estimates would cancel out. Since, in spite of this, regular results were obtained, the phenomenon being observed was clearly not imaginary. In fact, though all observers have not been able to identify real Zeeman displacements, all those who have been able to identify them have found effects with the same sign.

Moreover, no convincing explanation of the observations has been given, other than the existence of a magnetic field. The phenomenon requiring explanation is a difference in polarization between the two wings of a spectral line. Effects producing a pure displacement or pure broadening of the line cannot explain the polarization; no one has yet suggested a satisfactory alternative to the explanation in terms of a magnetic field.

We may, however, doubt whether the field does fall off rapidly with increasing height, as originally suggested. Though all observers have agreed regarding the sign

* Hale, *Ap. J.*, **38**, 93, 1913; Hale, Seares, van Maanen and Ellerman, *Ap. J.*, **47**, 206, 1918; Seares, van Maanen and Ellerman, *Proc. Nat. Acad. Sci.*, **4**, 4, 1918, and **5**, 242, 1919; Langer, *P.A.S.P.*, **48**, 208, 1936; H. D. Babcock, *P.A.S.P.*, **53**, 237, 1941.

of the magnetic field, they have not agreed well regarding its magnitude; the magnitude observed seems to have depended to a large extent on the observer and, probably, on the conditions under which he has been observing. The difference between the results for strong and weak lines certainly need not be real.

The first explanation proposed for the field was that it arises from the rotation of the solar material, supposed to be electrically charged. This was examined by Brunt *, who showed that only about 10^{-15} of the Sun's field could be explained in this way. A second explanation was proposed by Larmor †, according to which there is a circulation in meridian planes in the solar interior; electric currents induced in the moving material by reason of the Sun's field are supposed to maintain that field in the same way as the magnetism of a dynamo magnet is maintained by the currents it itself generates. In an earlier paper ‡ I have examined this theory and shown that the mechanism proposed cannot unaided maintain the field. It is not impossible, however, that it may operate to magnify the field due to some other effect. Extremely small speeds of circulation (10^{-6} cm./sec.) are adequate to produce appreciable induced currents.

In this paper, the Sun's field is considered further. An adequate theory of the field is not found; but considerations are advanced which may make clearer the conditions which an adequate theory must satisfy.

2. I have recently considered in detail the electrical conductivity σ of an ionised gas.§ A formula roughly valid in the Sun's interior is

$$\sigma = 1{\cdot}35 \times 10^{-14} T^{\frac{3}{2}}/\bar{Z}' \qquad \text{E.M.U.} \qquad (1)$$

In this T is the temperature, and $\bar{Z}'$ is defined as follows. Let n be the number per unit volume of Z-fold ionized atoms in any region; then the mean degree of ionization of the material is defined as

$$\bar{Z} = \Sigma n Z^2/\Sigma n Z, \qquad (2)$$

the summations being over all types of ion present. $\bar{Z}'$ is a function of $\bar{Z}$, whose values in terms of $\bar{Z}$ are tabulated in the paper quoted above.|| In what follows, we adopt the value $\bar{Z}=7$, which a rough calculation suggests to be reasonable in the Sun's interior; this gives $Z'=2{\cdot}3$.

The variation of T with the distance from the centre of the Sun is assumed to be that found in a paper by Blanch, Lowan, Marshak and Bethe.¶ Using their results, the following table is obtained, giving σ in terms of $x=r/R$, where r is the distance from the centre and R is the Sun's radius.

TABLE I

x	$10^5\sigma$ (E.M.U.)	x	$10^5\sigma$
0	76·5	0·5	7·1
0·05	73·5	0·55	5·3
0·1	62	0·6	3·95
0·15	47·5	0·65	2·9
0·2	36	0·7	2·05
0·25	27	0·75	1·4
0·3	20·5	0·8	0·9
0·35	15·6	0·85	0·5
0·4	12·0	0·9	0·3
0·45	9·2	0·95	0·1

* *A.N.*, **196**, 169, 1913.

† *Brit. Ass. Rep.*, p. 159, 1919; *M.N.*, **94**, 469, 1934.

‡ *M.N.*, **94**, 39, 1934.

§ *Proc. Roy. Soc.*, A, **183**, 453, 1945. Equation (1) is equation (54) of that paper, with the numerical factor slightly reduced, because the encounter function $A_1(2)$ is rather smaller in the Sun's interior than near the surface.

|| *Loc. cit.* The table quoted is given at the end of section 8 of that paper.

¶ *Ap. J.*, **94**, 37, 1941. The data used are taken from Table I of this paper.

These figures enable us roughly to estimate the time of decay of the Sun's magnetic field, assuming it to decay only as a result of electromagnetic effects. According to Lamb *, the maximum time of decay of a magnetic field in a sphere of uniform conductivity σ, and of radius a, is $4\sigma a^2/\pi$. Taking a as half the radius of the Sun, and σ as 10^{-4} E.M.U., this is found to be 5.10^9 years. This is so long a time that it seems desirable to investigate the matter in more detail.

3. In electromagnetic units, the electromagnetic equations for a slowly varying field are

$$\text{curl } \mathbf{H} = 4\pi\mathbf{j}, \qquad \text{curl } \mathbf{E} = -\frac{\partial \mathbf{H}}{\partial t}, \qquad \mathbf{j} = \sigma\mathbf{E}. \tag{3}$$

Hence

$$4\pi\sigma\frac{\partial \mathbf{E}}{\partial t} = -\text{curl curl } \mathbf{E} = \nabla^2\mathbf{E}. \tag{4}$$

Suppose that the field decays like an exponential factor $e^{-t/\tau}$, and that it is axially symmetric. Let $\mathbf{r}$ be the (vector) displacement from the centre of the Sun, and $\mathbf{k}$ a unit vector parallel to the axis of symmetry of the field. We assume that $\mathbf{E}$ is of the form

$$\mathbf{E} = (\mathbf{k}_\wedge\mathbf{r})f(r)e^{-t/\tau}; \tag{5}$$

this implies that the electric currents flow in circles round the axis of the field, and that the lines of magnetic force are in planes through the axis. Then

$$\nabla^2\mathbf{E} = (\mathbf{k}_\wedge\mathbf{r})\left(f'' + \frac{4}{r}f'\right)e^{-t/\tau}$$

and so (4) reduces to

$$f'' + \frac{4}{r}f' = -\frac{4\pi\sigma}{\tau}f. \tag{6}$$

This equation is equivalent to the two first-order equations

$$\chi' = -\frac{4\pi\sigma}{\tau}rf, \qquad \frac{d}{dr}(r^3 f) = r^2\chi. \tag{7}$$

Outside the boundary ($r = R$) of the Sun, $\mathbf{H}$ reduces to a dipole field

$$\mathbf{H} = -\text{grad}\,(M\mathbf{k}.\mathbf{r}/r^3) = \text{curl}\,(M\mathbf{k}_\wedge\mathbf{r}/r^3).$$

Hence $\mathbf{E}$ is of the form

$$\mathbf{E} = -\frac{M}{\tau r^3}\mathbf{k}_\wedge\mathbf{r},$$

i.e. $f(r)$ is proportional to $1/r^3$ outside $r = R$. Thus the boundary condition to be satisfied at $r = R$ is

$$rf' + 3f = 0 \tag{8}$$

or, by the second of equations (7),

$$\chi = 0. \tag{8'}$$

It is possible to find a solution of (6), finite at $r = 0$, and satisfying (8) at $r = R$, only if τ has one of an infinite set of values. Equation (6) is, in fact, similar in form to the differential equations giving the periods of vibration of a continuous system. We require the least "eigen-value" τ^{-1} of equation (6); this corresponds to the part of the field which decays slowest.

* *Phil. Trans.*, **174**, 519, 1883.

In practice we study (6) and (7) in the non-dimensional forms

$$f'' + \frac{4}{x}f' = -\frac{4\pi\sigma R^2}{\tau}f \equiv -\beta\sigma f, \tag{6'}$$

$$\chi' = -\beta\sigma x f, \qquad \frac{d}{dx}(x^3 f) = x^2\chi, \tag{7'}$$

where, as before, x denotes the non-dimensional variable r/R, and dashes now denote differentiations with respect to x. The boundary condition is that $\chi = 0$ when $x = 1$.

4. In solving (6') and (7'), we may use any of the known methods of obtaining the periods of vibration of a continuous system. One of these is based on Rayleigh's principle.* In the present connection, this principle states that the least value of β for which the equation

$$\frac{d}{dx}\left(\frac{1}{\sigma}\chi' x^2\right) = -\beta x^2\chi \tag{9}$$

(equivalent to (7')) possesses a solution, finite at $x = 0$ and vanishing at $x = 1$, is the least value of the ratio

$$\int_0^1 \sigma^{-1}\chi'^2 x^2 dx \Big/ \int_0^1 \chi^2 x^2 dx \tag{10}$$

when χ is a regular function of x in the range $0 \leqslant x \leqslant 1$, and vanishes at $x = 1$.

Near $x = 1$, $\sigma \propto (1-x)^{\frac{3}{2}}$; hence, from (9), $\chi' \propto (1-x)^{\frac{3}{2}}$, $\chi \propto (1-x)^{\frac{5}{2}}$. We therefore assume in turn

$$\chi = A(1-x)^{\frac{5}{2}},$$
$$\chi = A(1-x)^{\frac{5}{2}} + B(1-x)^{\frac{7}{2}},$$
$$\chi = A(1-x)^{\frac{5}{2}} + B(1-x)^{\frac{7}{2}} + C(1-x)^{\frac{9}{2}},$$
$$\cdots\cdots\cdots$$

adjusting the ratios $A : B : C : \ldots$ to make (10) a minimum. This gives reasonably accurate values for β; the value of χ is, however, not well determined, and even in determining β the numerical work is surprisingly laborious.

A second method, which gives reasonably good values for f and χ as well as β, is that of iteration. Preliminary work with Rayleigh's method suggested that $\chi_1 \equiv (1-x)^4$ is a better first approximation to χ than $(1-x)^{\frac{5}{2}}$. Successive approximations to χ and f are then determined by the equations

$$x^3 f_1 = \int_0^x \chi_1 x^2 dx, \qquad \chi_2 = \int_x^1 \beta_1 \sigma x f_1 dx,$$
$$x^3 f_2 = \int_0^x \chi_2 x^2 dx, \qquad \chi_3 = \int_x^1 \beta_2 \sigma x f_2 dx,$$

etc. The quantities $\beta_1, \beta_2, \ldots$, which give successive approximations to β, are found by imposing the condition $\chi_r = 1$ when $x = 0$ for all values of r.

Rayleigh's principle gave successively

$$\beta = 3{\cdot}2 \times 10^5, \qquad 2{\cdot}2 \times 10^5, \qquad 2 \times 10^5, \qquad \ldots \qquad \text{cm.}^2/\text{sec.}$$

The poorness of the first approximation to β is due to the poor representation of the actual χ by $\chi = A(1-x)^{\frac{5}{2}}$. Iteration gave successively

$$\beta = 2{\cdot}2 \times 10^5, \qquad 1{\cdot}96 \times 10^5, \qquad 1{\cdot}98 \times 10^5, \qquad \ldots, \qquad 2 \times 10^5 \text{ cm.}^2/\text{sec.}$$

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* For a recent astrophysical application of this principle, see Pekeris and Ledoux, *Ap. J.*, 94, 124, 1941.

Taking $\beta = 2 \times 10^5$ cm.^{2}/sec., we find

$$\tau = 4\pi R^2 \beta^{-1} = 3{\cdot}1 \times 10^{17} \text{ sec.} = 10^{10} \text{ years.}$$

Thus the time of decay of the field is of the order of the time-scale of the expanding universe. That is, if the universe were in a different state some 10^{10} years back, the magnetic field might be a relic of that state.

I do not feel altogether happy in making this suggestion, since the assumption that the magnetic field is explained by some unassigned cause operative a long time ago is, essentially, a confession of ignorance. Moreover, in the above the field has been assumed to decay solely as a result of electromagnetic effects. If the central part of the Sun is in a state of turbulent motion, this must affect the field. Convected material

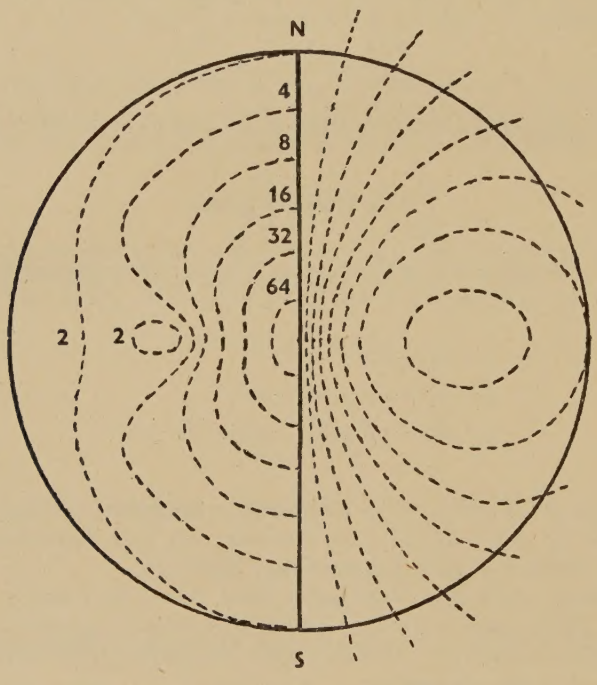

FIG. 1.—*Lines of force (right half) and constant magnetic intensity (left half) of the decaying field in a plane through the magnetic axis. The magnetic intensity is given as a multiple of the equatorial intensity at the surface.*

tends to carry its magnetic field with it. Thus turbulent motion may split up the field into a number of lesser elements, which may be destroyed in detail at a much faster rate than is indicated by the above calculation, much as the kinetic energy of mass motion is more rapidly dissipated by turbulence than by ordinary viscosity. The argument is not altogether certain: electromagnetic induction always acts to oppose the motion to which it is due, and in consequence effects expected from it often fail to materialize; moreover, some motions may actually reduce the rate of decay. We conclude, therefore, that it is not impossible that the Sun's magnetic field may be a relic from a previous era; but no more positive assertion is justified.

The lines of force, and lines of constant magnetic intensity, of the decaying field in a plane through the axis of symmetry, are shown in the accompanying figure. The intensity at the centre of the Sun is about 80 times that at the equator at the surface. Taking the latter as 25 gauss, the central field is 2000 gauss; save in the central core, the field is at most one or two hundred gauss. On this showing, the magnetic field of

sunspots can hardly be due solely to the convection of the general field with rising material from deep layers.

5. We consider next the possibility that the Sun's general field may be due to thermal effects in a rotating mass.* Ordinary thermo-electric effects, due to the relative inclination of isothermal and isobaric surfaces, can be ignored; any electric currents they might produce would be in planes through the axis of rotation, and would result in a field directed in circles round that axis. We consider instead a field due to convection in an unstable central region. Here hot gases rise, cool gases sink; during their vertical motion they are subject to a Coriolis force $-2\Omega_{\wedge}\mathbf{v}$ per unit mass, where Ω is the Sun's angular velocity and $\mathbf{v}$ the vertical velocity. This tends to deflect their motion to the east or west.

Suppose now that a mass of rising gas finds itself to the west of a mass of falling gas. The rising gas is deflected to the west, the falling to the east, by the Coriolis forces; hence they tend to move apart, and to balance the Coriolis forces a region of low pressure tends to be set up between them. Similarly when rising gas is to the east of falling gas, there tends to be a region of high pressure between them. In either case, pressure in the rising gas tends to be higher on its west side than on its east side; that in the falling gas to be higher on the east side than on the west.

A pressure gradient causes relative diffusion of electrons and ions, and so produces electric currents. A horizontal electron-pressure gradient $\partial p_e/\partial x$ is equivalent, for this purpose, to an electric force

$$-\frac{1}{en_e}\frac{\partial p_e}{\partial x}, \tag{11}$$

where $-e$ is the electronic charge, and n_e is the electron number-density. Suppose that the rising and falling masses of gas have equal dimensions in the x-direction; then $\partial p_e/\partial x$ has the same magnitude in the two. However, because the rising gas is the hotter, and the pressures in rising and falling gases are the same at a given level, n_e is smaller in the rising gas than in the falling. Hence the effective electric force (11) is rather greater in the rising gas, and, on the whole, currents tend to flow round the axis of the Sun in the direction of the electric force in the rising gas, *i.e.* from east to west. This produces a magnetic field which, at the Sun's surface, is from south to north; this is the observed sign.

This result does not actually depend on the assumption that the rising and falling gas-masses have equal dimensions in the x-direction. The effective E.M.F. driving currents round a circle round the Sun's axis is

$$-\int\frac{1}{en_e}\frac{\partial p_e}{\partial x}\,dx = -\int\frac{1}{en_e}dp_e,$$

which is independent of the dimensions in the x-direction, and depends only on the fluctuations in n_e and p_e on the circle. It is, however, convenient in calculations to continue to make the assumption. Then the mean effective electric force, averaged over one rising and one falling mass, is

$$-\frac{1}{2e}\left\{\left(\frac{1}{n_e}\frac{\partial p_e}{\partial x}\right)_{\text{rising}}+\left(\frac{1}{n_e}\frac{\partial p_e}{\partial x}\right)_{\text{falling}}\right\}=\left(\frac{k}{2ep_e}\frac{\partial p_e}{\partial x}\right)_{\text{rising}}\{-T_{\text{rising}}+T_{\text{falling}}\}$$

$$=-\frac{k\Delta T}{2ep_e}\frac{\partial p_e}{\partial x}, \quad \text{say.}$$

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* The ideas set forward here are similar to those advanced, in a less developed form, by W. M. Elsasser in *Phys. Rev.*, **55**, 489, 1939, to explain the Earth's magnetic field.

In this, $\frac{1}{p_e}\frac{\partial p_e}{\partial x}$ is approximately $\frac{1}{p}\frac{\partial p}{\partial x}$, and $\frac{\partial p}{\partial x}$ balances the Coriolis force $2\rho\Omega v$; also, if m is the mean molecular mass, $p = k\rho T/m$. Hence the mean electric force is

$$\frac{m\Delta T}{eT}\Omega v.$$

We put $\Delta T/T = 10^{-7}$, $v = 2 \times 10^3$ cm./sec., figures whose order of magnitude is suggested by results given by the author in an earlier paper *; these figures may separately be somewhat uncertain, but their product, which is proportional to the total transport of energy by convection, is fairly accurately determinate. Then, taking $m = 3 \times 10^{-24}$ gr., $\Omega = 3 \times 10^{-6}$ radians/sec., the mean electric force is found to be 10^{-13} E.M.U. With a conductivity of order 10^{-4} E.M.U., such an electric force leads to a magnetic field which, at the Sun's surface, is less than 10^{-6} gauss.

This estimate is, of course, correct only as regards order of magnitude. In particular, the introduction of Coriolis forces tacitly implies the assumption that the Sun's angular velocity is uniform throughout the interior of the Sun, and this assumption is almost certain to be invalid. Nevertheless, errors introduced by this and similar assumptions cannot affect the order of magnitude, and we may therefore assert that currents of thermal origin cannot give rise to the observed field. The reason is simply that appeal has to be made to second-order effects, depending not only on small thermal currents but also on the small Coriolis forces.

6. One may ask whether the small field due to thermal currents may act as the seed whence larger fields may grow by dynamo action, due to the circulation of material in meridian planes (section 1). I have not examined this suggestion in detail; but it is easy to show that dynamo action, if able to produce the observed field, must take an abnormally large time to do so.

We again consider a field possessing symmetry about an axis, with the lines of force in planes through the axis. On a special circle C in the equatorial plane of the field, the magnetic field vanishes; if N is the total magnetic induction from north to south through a closed curve, N has its maximum value N_c when the closed curve coincides with C. Near C, lines of force thread round C; the magnetic field is from north to south inside C and from south to north outside C. This implies that currents must flow round the axis of the field from east to west near C.

The E.M.F. tending to drive currents round C is the sum of the effective E.M.F. V of thermal origin, and the back E.M.F. $-dN_c/dt$ due to induction. In this, dN_c/dt is at first sight not the rate of change of the magnetic induction through C itself, but the rate of change of that through a fixed curve instantaneously coinciding with C (C may alter in radius with the time); but these two are actually identical, because N is maximum on C and so unaltered in passing to a neighbouring circle. Because there is a current from east to west round C

$$V - \frac{dN_c}{dt} > 0$$

and so

$$\frac{dN_c}{dt} < V \sim 10^{-2} \text{ E.M.U.}$$

Again, N_c must exceed the total magnetic induction across one hemisphere of the Sun's surface, which may be estimated as (say) 5×10^{23} E.M.U. Hence the time needed to produce the present field must exceed 5×10^{25} sec. $= 1{\cdot}6 \times 10^{18}$ years. This is so much greater than accepted estimates of the Sun's lifetime as to make the hypothesis unacceptable.

* *M.N.*, **96**, 42, 1935. The modifications of these results arising from the rotation of the Sun are discussed below in the Appendix to this paper.

Precisely the same argument shows that no effect too small to explain the Sun's field by itself can be magnified by dynamo currents to give the observed field in a time of order 10^{10} years. For 10^{10} years is not only the time of decay of the Sun's field when left to decay; it is also the time which the field needs to grow into something like its steady-state value when field-producing currents flow. Dynamo currents may be able to lift the "ceiling" that can be reached by the field; but, by the argument used above, they cannot increase the rate of growth of the field. If the "ceiling" is lifted, the time of reaching it must be correspondingly increased.

7. There seems, therefore, to be no possibility of progress along the lines which we have been considering. Thermo-electric effects produce too small a current. Dynamo effects do not help the field to grow near the locus where the magnetic field vanishes, and new lines of force have to be generated on this locus. Theories using the Hall or Nernst effects can be ruled out for the same reason.

There remain the following possibilities. In the above, the field was assumed to be in general shape similar to that of a uniformly magnetized sphere. It was supposed to possess an axis of symmetry, the lines of force lying in planes through that axis. Such a field can grow only by the production of new lines of force, which have to be generated on the locus on which the magnetic field vanishes.

If a more general type of magnetic field is considered, it is possible for the field to grow, not by the production of new lines of force, but by more efficient use of lines of force already existing. Because of the high conductivity of solar material, lines of force are effectively "frozen" into the material; when convection occurs, the lines of force are convected with the material. If the lines of force are pulled out into longer curves as a consequence of convection, they produce a larger total magnetic field. This fact was used recently by Alfvén * in developing a theory of the magnetic field of sunspots; he supposed that a strong magnetic field is produced locally by the extension in a given direction of lines of force of the general magnetic field, owing to convection in that direction, the strong magnetic field being then transported to the Sun's surface by a wave motion along the lines of force. We do not desire to consider here the validity of Alfvén's theory; but there is no doubt that strong local fields can be produced by extending already existing lines of force by convection.

In our problem, in order to multiply the Sun's general magnetic field, it is necessary to use the same lines of force over and over again. For example, consider a line of force round a circle with the Sun's axis as axis of symmetry. Suppose that, as a result of convection, this is twisted into a spiral wound on an anchor ring with the original circle as its central line. Then a field will have been produced in meridian planes, whose magnitude depends only on how tightly the spiral is wound. It is easy to imagine distortions of this type, which are able locally to produce strong fields. It is more difficult to imagine a distortion which will reinforce the field as a whole, and still more difficult to imagine a convection which will produce the required distortion. Nevertheless, because of the smallness of the convection currents needed, the possibility must be considered.

A second possibility is that material in the far interior of the Sun is capable of permanent magnetisation. This demands that very hot and ionized material is capable of acquiring a regular, crystal-like structure, a possibility normally disregarded. In view of the difficulties of other hypotheses, the possibility may, however, be worthy of further study.

Appendix

Turbulence and the Sun's Rotation.—In section 5, turbulent convection was assumed not to be materially impeded by the Sun's rotation. It has often been stated that

* *Arkiv. f. Mat., Ast., och Fys.*, **29A**, nos. 11 and 12, 1943; *M.N.*, **105**, 3, 1945.

rotation in a star has a stabilising influence; G. Randers has recently * suggested that in consequence turbulence will not appear near the equatorial plane of the Sun. His argument appears to be unsatisfactory, for two reasons. First, he ignores the possible effect of pressure gradients of the type envisaged in section 5. Second, he uses my estimate of the excess of the temperature gradient above the adiabatic, made ignoring the rotation. This estimate was based on two equations †, one of which balanced the kinetic energy dissipated by viscosity against that created by the instability of the gas. If rotation does exert a stabilising influence, this equation will have to be modified; its modified form must indicate a radial temperature gradient rather larger than that required to overcome the stabilising influence, though still only insignificantly greater than the adiabatic gradient. Randers's argument is invalidated by this modification.

A similar argument has been used by C. Walén ‡ in connection with Alfvén's theory of sunspots. He supposes that the sunspot cycle has its origin in alternate periods of quiescence and turbulence in the Sun's interior. During a quiet period, turbulence is prevented by the stabilising influence of rotation; the excess heat conveyed away by radiation accumulates in the Sun's core, until at last the temperature gradient becomes large enough to overcome the effect of rotation, and there is an outburst of turbulence. This outburst removes the excess heat, and leaves the Sun's core in its original stable state.

The argument implies a sort of oscillation about equilibrium. The equilibrium state is, in this case, one in which turbulence is just sufficiently violent to remove excess energy generated in the Sun's core, and the unstable temperature gradient is just great enough to overcome the stabilising effect of rotation and generate enough kinetic energy to balance that destroyed by viscosity. One may ask why this equilibrium state should ever be overshot. Walén assumes that an outburst of turbulence reduces the temperature gradient to the adiabatic value and then dies away. In fact, however, turbulence begins to be destroyed by viscosity faster than it is created, rather before the temperature gradient is reduced to such a value that the effect of rotation balances the instability due to the temperature gradient. When the turbulence begins to diminish, the convective transport of energy is reduced, and the reduction in the temperature gradient is checked. In consequence, the turbulent velocities and the temperature gradient steadily approach their equilibrium values, and cannot overshoot them. Walén's argument resembles terrestrial arguments criticised by Jeffreys §, which suggest oscillations about equilibrium due to thermal conduction, whereas thermal conduction cannot of itself produce oscillations, but only cause steady approach to an equilibrium state.

University College of North Wales,
Bangor :
1945 *July* 3.

* *Ap. J.*, 95, 454, 1942.

† *M.N.*, 96, 42, 1935, equations 31 and 34. The equation referred to above is the second of these.

‡ *Arkiv. f. Mat., Ast., och Fys.*, 30A, no. 15, 1944.

§ *The Earth*, p. 323, Cambridge, 1929.

NOTE ON THE ORIGIN OF THE SOLAR SYSTEM

F. Hoyle

(Received 1945 April 17)

Summary

The theory of the origin of the solar system given in a previous paper is discussed in relation to the results obtained from a study of the Crab nebula. It is shown that the requirements of the theory are satisfied with a considerable margin of safety when assumptions made in the previous work are replaced by observational data.

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1. *Introduction.*—In a recent paper * I suggested that a theory of the origin of the solar system could be obtained from the consideration of a binary star in which one of the components becomes a nova. It can be shown that the dynamical and physical requirements of the problem can be satisfied in such a theory. The most important requirements that the nova must satisfy are:

(*a*) The recoil on the parent star due to the outburst must be sufficiently large to break up the binary system.

(*b*) The mass of the diffuse gaseous material thrown off in the outburst must be large compared with the mass of the planets, since the high average velocity of expulsion makes it certain that the Sun can only capture a small proportion of the total mass thrown off by the star (for the case discussed in the former paper about 1 per cent. of the total mass expelled is captured by the Sun).

(*c*) The heating of the diffuse material captured by the Sun due to the absorption of radiation from the parent star must not lead to thermal velocities in the material that are greater than the velocity of escape from the Sun.

Since writing my earlier paper I have had the opportunity of discussing the interesting properties of the Crab nebula with Dr. W. Baade and Dr. R. Minkowski who have made a detailed study of this remarkable nebula † (there seems to be no doubt that the nebulosity arises from the excitation of material thrown off by the super-nova of 1054, the excitation being due to the parent star). As a result of this discussion it occurred to me that many of the assumptions previously made could be replaced by observational data. For the Sun can be regarded as possessing a binary companion that undergoes an outburst exactly similar to that of the supernova of 1054. The separation of the components in this binary will be taken as comparable with the radius of Jupiter's orbit. The advantage of considering this case is that the numerical values deduced from observations of the Crab nebula can be used for such quantities as the mass of the material thrown off in the outburst, or the surface temperature and luminosity of the remaining nucleus after the outburst. Thus it is possible to relate the postulated requirements of the theory of the origin of the solar system to conditions that can be directly observed. It is clear that the theory must derive added force from this relation with observation.

The present theory differs from the previous discussion (*loc. cit.*) in that the binary companion of the Sun is here taken to be a supernova with properties similar to the

* F. Hoyle, *Proc. Camb. Phil. Soc.*, 40, 256, 1944.

† W. Baade, *Ap. J.*, 96, 188, 1942; R. Minkowski, *Ap. J.*, 96, 199, 1942.

Crab nebula, whereas in the former work it was supposed that the binary companion was a star which, under conditions of rotational instability, divided into two pieces with diffuse material trailing between them. The form of the outburst has different characteristics in these two cases, for although the marked departure from spherical symmetry shown by photographs of the Crab nebula confirms the suggestion that rotational instability is the cause of the outburst, it is certain that the star does not divide into two pieces. The material is thrown to infinity, as was suggested by Lyttleton *, but the material is thrown off in a diffuse form and not as a compact body. Indeed the process of rotational instability in stars seems to be markedly different from results based on the work of Poincaré, Darwin, Liapounoff and Jeans (which make simplifying assumptions concerning the physical properties of stellar material). The way in which material is thrown off seems to be more similar to the process discussed by Kuiper in connection with the β Lyræ system † in which material flows through a neutral point at the surface of the star.

2. It has been shown by Minkowski (*loc. cit.*) that the mass of diffuse material in the Crab nebula is of order 15 $M_\odot$ so that the requirement (*b*) is satisfied by a large margin (it seems probable that the supernova of 1054 could have produced planets considerably more massive than Jupiter). Furthermore, since an appreciable fraction of the mass of the star is thrown off with a velocity of order 1000 km. per sec. it is clear that an asymmetry of a few per cent. in the way in which material is thrown off in the plane of rotation would be sufficient to satisfy the requirement (*a*). The assumption that some degree of asymmetry occurs is supported by the observed irregularity in shape of the amorphous inner region of the Crab nebula which suggests that the material was not thrown off with complete symmetry. Accordingly it is reasonable to suppose that the recoil on the parent star would be sufficient to break up a binary system with a separation comparable with the radius of Jupiter's orbit. The velocity of recoil will probably be considerably less, however, than was supposed in my former paper. This means that the time taken for the parent star to recede from the solar system will be much greater than the previous estimate of 10 days. The chief effect of this change is to alter the discussion of the requirement (*c*). This will now be considered.

If an asymmetry of 10 per cent. is assumed as giving a reasonable estimate, the velocity of recoil will be about 50 km. per sec. in the case where the star throws off half its original mass. The time taken for the parent star to reach the outskirts of the solar system (30 astronomical units from the Sun) is then about 3 years. The absolute bolometric luminosity of the parent star at this stage can be deduced from the properties of the Crab nebula by means of the following argument. The present absolute photographic magnitude of the parent star of the Crab nebula is about 4·8 (*cf.* W. Baade, *loc. cit.*) so that the parent star is now about 21 magnitudes fainter in the photographic region than the value of $-16{\cdot}5$ attained at the height of the outburst. Thus since it is known ‡ that in 3 years the absolute photographic magnitude of a supernova declines by about 19 magnitudes, it follows that in 3 years the absolute photographic magnitude of the parent star of the Crab nebula would be expected to decline from $-16{\cdot}5$ to a value comparable with its present magnitude, and consequently it is reasonable to suppose that the bolometric luminosity 3 years after the outburst would be comparable with its present value, which has been shown by Minkowski to be of order $10^4\,L_\odot$, where $L_\odot$ is the solar luminosity. This result has an important application to the requirement (*c*) for it indicates that the parent star of the planets would have a luminosity of about $10^4\,L_\odot$ at the time when it had receded to the outskirts of the solar system. Furthermore, at this stage the surface temperature will be comparable with the value of $5.10^{5\circ}$ A. estimated by Minkowski for the parent star of the Crab nebula. This value

* R. A. Lyttleton, *M.N.*, **98**, 646, 1938.
† G. P. Kuiper, *Ap. J.*, **93**, 133, 1941.
‡ W. Baade, *Ap. J.*, **97**, 119, 1943.

agrees very closely with the assumption of a surface temperature of $10^{6°}$ A. made in the previous paper.* On the other hand the luminosity of $10^4\ L_\odot$ is considerably less than the value formerly adopted. This difference is due to the radius of the parent star of the Crab nebula being only about $0{\cdot}02\ R_\odot$ (*cf.* Minkowski, *loc. cit.*) as against $R_\odot$ assumed in the previous paper. This means that the present situation is more favourable for satisfying the requirement (*c*).

The mean density of the diffuse material that must be captured by the Sun in order to form the planets may be estimated so far as order of magnitude is concerned by distributing the mass of the planets uniformly throughout a sphere of radius 10 astronomical units. This gives a value of about 10^{-13} grm. per cm.^{3}. Now a region of dimensions 10 astronomical units containing material of this density will be very opaque to the radiation from the parent star (that is, the cross-section for the absorption of a quantum multiplied by the number of atoms contained in a column of unit cross-section and length 10 astronomical units is large compared with unity). This means that the kinetic temperature of the diffuse material must be small compared with the surface temperature of the star since, as is well known, an assembly tends towards thermodynamic conditions when it is markedly opaque to radiation. It is therefore to be expected that the temperature of the diffuse material will be appreciably less than $10^{5°}$ A. Thus the thermal velocities of the atoms in the diffuse material will be small compared with the velocity of about 50 km. per sec. with which the parent star recedes from the Sun. This will be particularly the case for the heavy elements which comprise the main mass of the planets (it is of interest in this connection that the observations of the Crab nebula are consistent with the suggestion that the inner amorphous region contains only a small fraction by mass of hydrogen). Thus the heating effect of the parent star will be largely removed before any appreciable motion of the diffuse material can occur (an appreciable motion being a distance of order 10 astronomical units). It follows that the conversion of thermal energy into radiation within the diffuse material must reduce the thermal velocities of the atoms to values that are small compared with the velocity of escape from the Sun, and that this process will occur before any important motion of material has taken place. It is seen therefore that the material will not escape from the Sun since the heating effect of the parent star is removed long before any process of escape could be effective.

3. The only important assumption that remains in the present theory is that in addition to throwing off a large quantity of material with mass of order $15\ M_\odot$ (the velocity at infinity being about 1000 km. per sec.), the supernova also throws off a small amount of material of mass $10^{-3}\ M_\odot$ which the Sun is able to capture.† Although it is clearly plausible to suppose that the velocity of ejection of material does not fall discontinuously from 1000 km. per sec. to zero at the end of the outburst, it is necessary to show that no conflict with observation arises from this assumption.

Consider a supernova, not a member of a binary system, and let a mass M of material be moving outwards from the parent star with velocity v. At time t after the outburst the material will occupy a region of radius vt, and since the cross-section for the absorption of a high energy quantum emitted by the parent star is of order 10^{-20} it is seen that the expanding material will be opaque to the radiation from the star if

$$M/4\pi(vt)^2 m_H \mu \geqslant 10^{20}, \qquad (1)$$

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* *N.B.*—The value of the surface temperature is misprinted as $10^{5°}$ A. instead of $10^{6°}$ A. in this paper.

† For the Sun to capture material ejected by the supernova, the velocity of ejection must be approximately equal in magnitude and opposite in direction to the velocity of recoil of the supernova from the Sun. Thus for a velocity of recoil of 50 km. per sec., the material captured by the Sun must have a velocity of ejection from the supernova of about 50 km. per sec., which is small compared with the velocity of ejection of the main mass of the material (1000 km. per sec.).

where m_H is the mass of the hydrogen atom, and μ is the mean atomic weight of the material. For the Crab nebula put $M = 15\ M_\odot$, $v = 10^8$ cm. per sec., $t = 3.10^{10}$ sec., and $\mu = 6$. Then $M/4\pi(vt)^2 m_H \mu$ is about 3.10^{19} so that an appreciable proportion of the radiation from the parent star will be absorbed in the Crab nebula.

Now it is necessary in the present theory of the origin of the solar system that the small quantity of material assumed to be thrown off with a velocity of about 50 km. per sec. shall not form a small region surrounding the star that is opaque to radiation from the star.* Putting $M = 10^{-3}\ M_\odot$, $v = 50$ km. per sec., $t = 3.10^{10}$ sec., $\mu = 6$ gives about 10^{18} for $M/4\pi(vt)^2 m_H \mu$, so that this requirement is satisfied. At the same time it might appear that an opaque region could be formed if a quantity of material were thrown off with sufficiently small velocity. For example if $M = 10^{-3}\ M_\odot$, $v = 1$ km. per sec., the condition (1) would be satisfied and the region formed by this material would apparently be opaque. It is easy to see, however, that this situation could never arise, for if the region in question is opaque the material in the region will be accelerated outwards by radiation pressure. The mean outward acceleration due to radiation pressure will then be of order L/cM, where c is the velocity of light and L is the bolometric luminosity of the parent star. Thus the outward velocity of the material after a time t due to this acceleration is Lt/cM cm. per sec. Putting $t = 3.10^{10}$ sec., $M = 10^{-3}\ M_\odot$ and $L = 10^4\ L_\odot$ gives a velocity of 200 km. per sec. It is clear, therefore, that radiation pressure will prevent the formation of an inner opaque region of slowly moving material. Accordingly there is no conflict with observation in assuming that a small quantity of material is thrown off with a velocity small compared with the general velocity of the outburst.

The acceleration L/cM may be compared with the acceleration $\gamma M_\odot/r^2$ due to the gravitational field of the Sun, where γ is the constant of gravitation and r is a radial co-ordinate that measures distance from the Sun. Thus putting $r = 10^{14}$ cm., $M = 2.10^{30}$ grm., $L = 4.10^{37}$ ergs per sec., it is seen that the acceleration acting on the diffuse planetary material due to the gravitational field of the Sun is more than 10 times as large as the acceleration arising from the absorption of radiation from the parent star. Thus radiation pressure will not prevent the capture of diffuse planetary material by the Sun. It is of interest that radiation pressure might prevent capture of diffuse material if $r > 3.10^{14}$ cm. (that is, r greater than about 20 astronomical units). This suggests that the main mass of the planetary material must lie within 20 astronomical units from the Sun.

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1945 *April* 16.

* For the Sun to capture material ejected by the supernova, the velocity of ejection must be approximately equal in magnitude and opposite in direction to the velocity of recoil of the supernova from the Sun. Thus for a velocity of recoil of 50 km. per sec., the material captured by the Sun must have a velocity of ejection from the supernova of about 50 km. per sec., which is small compared with the velocity of ejection of the main mass of the material (1000 km. per sec.).

OCCULTATIONS OBSERVED AT THE RADCLIFFE OBSERVATORY, PRETORIA, IN THE YEARS 1939 to 1944

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As a war measure and pending the completion of the 74-inch reflector, routine observations of lunar occultations have been made, and the observing list has contained, besides the N.A. stars, a number of fainter ones for which predictions have been made for Johannesburg and kindly supplied to us by the Union Observatory. Even if positions of these fainter stars, of an accuracy comparable with those in the NZC, are not yet available, it may not be long before many of them are so, and consequently it seemed worth while observing them. In the meantime their positions have been taken from the most recent catalogues available, and systematic corrections have been applied to them, whenever possible, to reduce them to the system of the NZC. The adopted mean positions, which include proper motion to date, are given in Table II.

The occultations, in each case disappearance at the dark limb, were observed with the $4\frac{1}{2}$-inch finder of the reflector or, when the altitude of the Moon was less than about 30°, with a 3-inch altazimuth, formerly the property of the 7th Duke of Marlborough to whom the objective was given by Sir James South in 1844. With the exceptions that the late E. G. Williams observed six of the earlier occultations and R. O. Redman those in 1943 November and December, all the observations were made and reduced by H. Knox-Shaw.

N.A. stars are marked in Table I by an asterisk. In reducing these stars the positions (or constants) given in the N.A. were used. Innes's method of reduction was employed for the fainter stars throughout and for all the stars in 1943 and 1944. For the year 1939 and 1940 the observed times of disappearance given in Table I were increased by 0·00076 hour when calculating p, q and $\Delta\sigma$.

TABLE I

Date	Name or BD No.	NZC	U.T.	p	q	$\Delta\sigma$	Coeff. of $\Delta\alpha$	Coeff. of $\Delta\delta$
1939			h m s			″		
Nov. 14	−18° 4871		17 13 13·7	0·88	+ ·47	−2·1	12·1	+ ·52
14	−18° 4886	2647*	18 03 44·6	·69	− ·73	+0·5	10·4	− ·68
19	51 Aqar	3287*	18 35 41·0	·84	+ ·54	−1·4	9·3	+ ·78
Dec. 16	− 7° 5708		18 45 02·8	·99	− ·14	−2·9	14·7	+ ·17
21	+11° 261	290*	18 08 29·4	·91	− ·42	−0·4	14·5	− ·17
1940								
Jan. 20	+18° 624	639*	21 11 25·1	1·00	− ·08	+0·9	14·2	+ ·02
21	+19° 898	796*	22 37 10·2	1·00	− ·01	+1·5	14·1	+ ·01
Feb. 15	+15° 430	450*	19 07 07·3	·80	+ ·60	−1·0	9·6	+ ·75
16	+17° 656		18 46 27·0	·77	− ·63	+0·1	12·2	− ·52
Apr. 12	+18° 783		16 42 52·2	·90	− ·44	+0·9	13·0	− ·41
14	+17° 1479	1072*	18 20 35·6	·83	− ·56	+0·7	10·9	− ·65
15	+16° 1589		16 44 14·7	·92	+ ·39	−0·6	14·0	+ ·22
15	+16° 1606		19 09 00·2	1·00	− ·09	+2·0	13·9	− ·27
May 11	+18° 1348		17 24 29·4	1·00	+ ·05	+1·0	14·2	− ·04
11	+18° 1349	1040*	17 31 25·7	·92	− ·40	−1·9	12·4	− ·49
12	+16° 1551	1176*	19 05 11·8	·82	+ ·58	−0·8	13·0	+ ·43
13	+14° 1929		16 15 17·7	·21	− ·98	0·0	− 0·2	−1·00
13	+14° 1930		16 19 05·2	·16	− ·99	−0·5	− 0·9	−1·00
June 12	+ 3° 2475	1624*	19 52 18·8	·94	− ·34	−0·9	11·8	− ·62
Aug. 10	o^2 Libr	2193*	19 16 45·4	1·00	− ·10	−0·5	13·9	− ·28

Date	Name or BD No.	NZC	U.T.	p	q	$\Delta\sigma$	Coeff. of $\Delta\alpha$	Coeff. of $\Delta\delta$
1940			h m s			"		
Aug. 11	−16° 4280	2352*	21 04 33·9	·68	+ ·73	−1·0	10·9	+ ·65
15	61 Sgtr	2913*	16 44 25·7	1·00	+ ·07	−1·4	14·0	+ ·23
Nov. 6	−12° 5890	3075*	20 45 16·4	·90	+ ·43	−1·5	11·4	+ ·63
1941								
Mar. 2	+ 9° 271	310	17 47 25·1	·76	− ·65	+0·1	13·3	− ·43
6	+18° 839		17 42 25·1	·99	− ·15	−0·3	14·1	− ·10
Apr. 2	+18° 777		16 34 24·1	·91	− ·41	−0·3	13·4	− ·34
3	+18° 1027		16 56 15·5	·80	+ ·60	+1·9	11·3	+ ·60
3	+18° 1036		17 44 55·4	·62	+ ·79	+1·6	8·7	+ ·79
3	+18° 1040	904*	18 18 48·5	·94	+ ·34	−0·2	13·3	+ ·34
3	+18° 1043		18 27 21·7	·94	+ ·34	+2·5	13·4	+ ·34
3	+18° 1046		18 47 10·7	·82	+ ·57	+1·0	11·7	+ ·57
8	48 Leon	1549*	21 36 19·1	1·00	+ ·01	+1·4	14·3	− ·28
9	τ Leon	1663*	19 20 05·1	·97	− ·26	+1·4	12·6	− ·55
May 1	+18° 1256		16 23 07·2	·85	+ ·53	−0·2	12·3	+ ·50
1	+18° 1258		16 26 41·2	·97	− ·25	+2·1	13·6	− ·29
3	+15° 1807		18 42 29·0	·96	+ ·26	−0·1	14·4	+ ·08
7	+ 1° 2636	1730*	19 08 42·0	·77	+ ·63	+0·3	14·0	+ ·36
June 2	37 Sext	1567*	18 47 29·9	1·00	+ ·02	+2·6	14·3	− ·28
2	+ 7° 2358	1573*	19 33 59·8	·89	+ ·45	+0·3	14·7	+ ·17
28	+12° 2067		16 14 17·9	·57	− ·82	+0·4	5·0	− ·94
29	+ 8° 2368		16 09 26·9	·98	− ·21	+3·4	13·0	− ·49
29	+ 8° 2367		16 18 25·2	·79	− ·61	+2·3	8·6	− ·81
29	+ 8° 2369	1538	16 29 48·2	·86	+ ·52	+0·4	14·4	+ ·25
29	+ 8° 2370		16 40 56·6	·99	+ ·11	+1·4	14·6	− ·18
30	+ 4° 2455		17 35 01·0	·98	+ ·18	+2·6	14·8	− ·13
30	+ 4° 2461	1657*	18 47 16·7	·99	− ·17	+3·1	13·3	− ·47
30	83 Leon	1660*	19 42 18·0	·68	− ·73	+2·6	6·4	− ·91
30	+ 3° 2503		19 43 35·3	·67	− ·75	+2·8	6·0	− ·92
July 1	+ 0° 2914		16 23 14·4	·96	− ·29	+1·0	12·2	− ·58
1	13 Virg	1770*	19 07 02·4	·30	+ ·95	−0·4	8·8	+ ·81
3	− 8° 3689	2016*	16 07 51·5	·87	− ·49	−0·9	10·4	− ·71
3	95 Virg	2022*	17 33 55·1	·97	+ ·26	+0·6	14·8	− ·02
6	−17° 4717	2460*	18 47 51·5	·90	+ ·44	−0·1	13·3	+ ·36
27	+ 5° 2451	1618	16 18 09·8	·99	+ ·14	+1·0	14·7	− ·17
27	+ 5° 2452		16 24 46·8	·90	+ ·44	+0·8	14·8	+ ·14
28	+ 1° 2640		16 19 54·1	·95	− ·31	+3·7	12·1	− ·59
28	+ 1° 2641		16 36 18·7	1·00	+ ·03	+2·7	14·4	− ·28
29	− 3° 3383		18 29 43·0	·57	+ ·82	+1·2	11·9	+ ·60
30	− 7° 3721		18 19 06·3	·58	+ ·82	−0·5	11·7	+ ·62
30	− 7° 3723		18 41 56·1	·94	− ·35	+0·6	11·9	− ·60
31	−11° 3814		18 51 10·5	·90	+ ·44	+2·0	14·4	+ ·21
31	−11° 3822		20 22 36·4	·97	+ ·26	+1·4	14·7	+ ·02
Aug. 3	−18° 4645	2555*	18 00 09·8	1·00	+ ·05	+1·1	14·3	+ ·02
26	− 6° 3850		17 14 53·5	·92	− ·39	−0·6	11·5	− ·64
28	−13° 4183		17 19 05·1	·94	− ·33	+0·3	12·5	− ·51
28	−13° 4188		18 10 06·2	·72	− ·69	+2·9	8·3	− ·82
28	−13° 4193		18 42 03·9	·92	+ ·40	−0·1	14·2	+ ·21
29	φ Ophi	2372*	17 41 41·9	1·00	− ·04	+1·1	14·2	− ·17
31	−17° 5203	2674*	16 37 12·3	·59	+ ·81	−0·9	8·3	+ ·82

Date	Name or BD No.	NZC	U.T.	p	q	$\Delta\sigma$	Coeff. of $\Delta\alpha$	Coeff. of $\Delta\delta$
1941			h m s			"		
Sept. 26	−17° 4753		17 18 26·4	·86	+ ·50	−1·1	12·9	+ ·44
26	−17° 4761		18 44 31·5	·97	− ·23	+1·1	13·6	− ·30
26	−17° 4773	2495*	20 17 20·5	·64	− ·77	−0·3	8·4	− ·81
Oct. 25	−17° 5381†		17 15 17·3	·84	+ ·54	−2·3	11·5	+ ·59
25	−17° 5388		17 57 07·3	·54	+ ·84	−0·7	6·9	+ ·88
25	−17° 5409	2768	19 31 33·8	1·00	+ ·08	+0·6	14·1	+ ·15
25	−17° 5414		20 00 42·6	·37	+ ·93	−1·3	4·4	+ ·95
26	−16° 5469		19 29 39·8	1·00	+ ·10	+0·3	14·0	+ ·24
27	−14° 5861		17 39 56·6	·36	+ ·93	−1·7	2·4	+ ·99
27	−14° 5866	3047	18 01 51·6	·89	− ·45	+1·2	14·0	− ·26
27	−14° 5867		18 13 15·3	1·00	+ ·10	+0·6	13·9	+ ·30
27	−14° 5871		18 52 40·2	·95	− ·30	+0·6	14·5	− ·10
27	−13° 5790		20 46 48·8	·87	+ ·50	−0·5	10·8	+ ·67
27	−13° 5793		20 51 22·7	·98	− ·20	+1·5	14·6	+ ·01
Nov. 24	−12° 6001		17 40 04·4	·99	− ·16	+1·6	14·6	+ ·07
24	−12° 6003		17 51 46·2	·93	+ ·36	−1·3	12·0	+ ·58
24	−12° 5998	3145*	17 51 52·6	·54	+ ·84	−0·7	4·8	+ ·95
24	−12° 6002		17 52 50·9	·57	− ·82	+2·4	11·0	− ·66
24	−12° 6005	3146*	18 23 09·4	·37	+ ·93	−0·5	1·9	+ ·99
Dec. 23	− 6° 6087	3357*	17 54 59·6	·98	+ ·20	+0·1	13·1	+ ·48
23	− 6° 6088		17 56 28·8	·95	− ·30	+0·8	14·9	·00
23	− 6° 6096		19 12 58·2	·89	+ ·47	−0·3	10·5	+ ·71
1942								
Feb. 21	+12° 436	454*	18 07 15·3	·99	− ·17	+0·6	14·6	+ ·06
Mar. 28	+13° 2117	1413*	20 42 37·6	·84	− ·54	+0·5	10·1	− ·72
Apr. 22	+18° 1636		18 21 07·8	·52	− ·85	+0·3	6·2	− ·90
28	γ^1 Virg	1821*	19 11 38·1	1·00	− ·10	+1·9	13·7	− ·41
28	− 0° 2603	1825*	20 33 47·6	·92	+ ·40	+0·3	14·9	+ ·09
May 19	+19° 1650		17 19 11·3	·85	+ ·52	−0·4	12·6	+ ·46
22	+13° 2145		17 13 37·4	·96	− ·28	+3·3	12·6	− ·50
22	+13° 2147		17 45 09·5	·98	− ·21	−1·2	13·1	− ·45
23	ρ Leon	1547*	16 37 11·4	·99	− ·11	+1·9	13·7	− ·39
June 17	+16° 1789		16 58 16·9	·97	− ·25	+0·8	13·1	− ·42
18	+14° 2097		16 02 58·6	·98	− ·20	+0·1	13·2	− ·42
18	+13° 2098		17 44 40·9	·64	− ·77	−0·2	6·4	− ·90
18	+14° 2101	1404	17 54 27·1	1·00	− ·03	+0·6	14·1	− ·26
20	+ 7° 2413		16 27 27·2	·79	− ·62	+2·3	8·4	− ·83
20	+ 7° 2417	1614	17 24 04·5	·91	− ·42	−1·1	11·0	− ·67
20	+ 7° 2421		18 49 54·8	·89	− ·45	−0·3	10·6	− ·70
23	− 5° 3762	1976*	20 42 04·1	·98	+ ·22	+1·2	14·9	− ·09
23	− 6° 3887	1978*	21 15 11·3	1·00	+ ·06	+1·7	14·5	− ·25
24	− 9° 3975	2089*	17 52 26·5	·89	− ·46	+1·6	10·8	− ·69
July 19	− 0° 2595		19 50 09·9	·97	+ ·25	+0·3	15·0	− ·08
20	− 3° 3461		16 06 15·9	·97	− ·23	+2·1	12·7	− ·53
20	− 3° 3462	1923*	16 16 19·0	·40	+ ·92	−0·6	10·0	+ ·74
20	− 3° 3470		18 02 03·2	·46	+ ·89	−0·1	10·7	+ ·70
20	− 4° 3487		18 30 52·1	1·00	+ ·01	+2·6	14·2	− ·30
20	− 4° 3485		18 39 42·4	·84	− ·54	0·0	9·4	− ·78
21	− 8° 3737	2043*	15 58 39·6	·52	− ·85	+2·0	3·7	− ·97
21	− 8° 3750		17 37 54·9	·46	− ·89	+1·4	2·8	− ·98

† Brighter star of pair observed.

Date	Name or BD No.	NZC	U.T.	p	q	$\Delta\sigma$	Coeff. of $\Delta\alpha$	Coeff. of $\Delta\delta$
1942			h m s			″		
July 22	−12° 4227	2184*	18 44 37·8	·67	− ·74	+1·2	6·9	− ·88
24	−17° 4759	2485*	17 50 11·7	·96	− ·28	−1·5	13·2	− ·38
24	−17° 4773	2495*	19 55 45·5	·65	+ ·76	−1·5	10·2	+ ·70
Aug. 16	− 2° 3651		17 26 28·2	·64	+ ·77	−0·1	12·7	+ ·53
17	− 7° 3762		17 30 54·9	·88	− ·47	+1·1	10·5	− ·71
18	−10° 3992		16 30 51·9	·61	+ ·79	−1·5	11·7	+ ·61
18	−10° 3993		16 32 52·9	·64	+ ·76	−0·4	12·1	+ ·57
18	−11° 3854		18 07 40·2	·90	− ·43	−0·1	11·2	− ·65
18	−11° 3862		19 03 26·6	·88	+ ·47	+0·1	14·3	+ ·23
19	−14° 4311		17 16 04·6	·79	− ·61	+2·0	9·4	− ·76
19	−14° 4314	2279*	17 35 31·2	·96	+ ·29	+0·1	14·4	+ ·09
22	−18° 5155	2764*	17 47 05·5	·96	− ·28	−1·5	13·7	− ·24
Sept. 16	−16° 4325		17 21 49·9	·82	+ ·57	−0·8	12·9	+ ·44
16	−16° 4327		18 25 35·2	·90	− ·45	+1·0	11·8	− ·57
18	−18° 5079	2731*	22 09 35·9	·57	− ·82	+1·4	8·4	− ·81
Oct. 14	−17° 4793		16 58 39·1	·84	+ ·54	+0·4	12·7	+ ·45
14	−17° 4797		17 23 19·3	1·00	− ·04	+2·2	14·1	− ·14
14	−18° 4524		18 04 00·0	·78	− ·63	+2·0	10·3	− ·69
15	−18° 4952		17 05 26·5	·97	+ ·25	0·0	13·8	+ ·24
15	−18° 4950		17 11 13·9	·78	+ ·62	−1·0	11·2	+ ·61
15	−18° 4953		17 35 31·2	·45	+ ·89	−1·4	6·5	+ ·89
15	−18° 4960		18 08 45·8	·61	+ ·79	−1·4	8·8	+ ·79
15	−18° 4965		18 22 58·4	·89	+ ·46	+0·3	12·6	+ ·46
15	−18° 4967		18 38 01·4	·52	+ ·86	−0·7	7·4	+ ·85
15	−19° 5007		18 42 56·4	·53	− ·85	+2·6	7·5	− ·85
15	−18° 4976		19 21 24·5	·78	+ ·63	−1·1	11·0	+ ·63
15	−18° 4982	2680*	19 54 33·1	·95	− ·32	−1·0	13·4	− ·33
15	−18° 4988	2686*	20 33 36·7	·72	+ ·69	−1·4	10·2	+ ·69
16	−18° 5373		18 39 16·9	·56	− ·83	+3·3	8·9	− ·78
20	ϕ Aqar	3412*	19 36 35·8	·70	− ·72	+0·8	13·2	− ·47
20	96 Aqar	3430*	23 13 42·5	·99	+ ·16	+0·1	13·3	+ ·46
Nov. 10	−17° 4700	2454*	17 40 46·8	·75	+ ·66	−1·5	11·7	+ ·57
11	−18° 4789	2613	17 39 57·5	·73	− ·68	+2·1	10·0	− ·71
13	−17° 5901		19 11 21·5	·97	+ ·23	−0·3	13·3	+ ·37
13	−17° 5913	2952	20 03 34·7	·99	− ·16	+0·8	14·3	− ·01
14	−14° 5949		18 41 28·0	·57	+ ·82	−0·5	5·6	+ ·92
14	−15° 5908	3100*	19 13 52·4	·93	− ·37	+1·1	14·3	− ·17
14	−15° 5911		19 39 22·6	·48	− ·88	+2·5	9·5	− ·75
14	−14° 5960		19 49 47·6	·89	− ·46	+2·1	14·0	− ·25
14	−14° 5956		19 53 18·6	·36	+ ·93	−0·7	2·2	+ ·99
15	−11° 5770	3252*	21 08 32·2	·73	− ·68	+0·7	13·1	− ·46
16	81 Aqar	3379*	19 46 56·7	·91	− ·42	+0·1	14·8	− ·12
16	− 7° 5911		20 02 10·4	·97	− ·23	+0·8	14·8	+ ·08
Dec. 13	− 9° 6039		17 43 13·4	·59	+ ·81	−1·0	4·9	+ ·94
13	− 9° 6054		19 05 18·6	·97	− ·24	+0·2	14·8	+ ·05
13	− 8° 5945		19 35 50·2	·97	+ ·23	−0·6	12·8	+ ·51
13	− 8° 5952	3346	20 13 23·3	1·00	− ·06	+0·2	14·4	+ ·24
17	+ 7° 324	308*	18 23 50·0	·66	− ·75	+1·2	12·9	− ·51
1943								
Jan. 10	− 6° 6191	3432*	18 54 07·5	·71	− ·70	+0·4	13·3	− ·45

Date	Name or BD No.	NZC	U.T.	p	q	$\Delta\sigma$	Coeff. of $\Delta\alpha$	Coeff. of $\Delta\delta$
1943			h m s			"		
Jan. 12	+ 2° 149		18 48 19·4	·90	+ ·44	−0·9	10·5	+ ·71
Feb. 8	+ 0° 106		17 39 05·3	·76	− ·65	+0·3	14·0	− ·36
8	+ 0° 107		17 40 10·7	·84	− ·54	+1·5	14·6	− ·23
Mar. 9	+ 7° 313	298*	17 04 16·7	·78	− ·62	+0·8	13·9	− ·35
12	+17° 751	689	17 13 03·2	·48	+ ·87	+0·2	4·7	+ ·94
14	+19° 1308		19 55 47·1	·99	+ ·15	+0·6	13·9	+ ·17
16	+19° 1896	1202*	18 38 41·8	·94	+ ·33	+0·1	13·8	+ ·22
Apr. 9	+18° 783		18 46 01·6	·80	+ ·60	+0·5	10·2	+ ·70
11	+20° 1596		18 37 43·4	·92	− ·40	−1·1	12·8	− ·42
14	+15° 2027	1385*	18 22 23·0	·85	− ·52	−0·8	10·4	− ·70
May 8	ν Gemi	995*	15 45 21·6	·81	− ·59	−0·1	11·5	− ·57
8	+20° 1454		16 52 20·5	·89	+ ·45	−0·1	12·5	+ ·46
10	+18° 1869		17 21 57·4	·56	− ·83	0·0	6·4	− ·89
12	+14° 2157		17 04 04·3	·86	+ ·50	+1·6	14·0	+ ·27
June 6	+19° 1869		16 21 31·5	·78	− ·63	+1·2	10·0	− ·71
6	+19° 1872		16 46 32·5	1·00	+ ·08	+0·7	14·1	− ·03
7	+18° 2037		17 27 16·7	·99	− ·12	+0·1	13·7	− ·29
7	+17° 1941	1319*	18 25 51·1	1·00	+ ·05	+0·9	14·2	− ·13
8	+15° 2075		18 02 10·9	·81	− ·58	+0·5	9·5	− ·75
10	+ 9° 2465		18 42 24·9	·72	+ ·70	+0·8	13·4	+ ·43
11	+ 4° 2549		17 36 21·3	·45	− ·89	+1·4	1·9	− ·99
11	+ 4° 2556	1733*	20 03 18·8	·80	− ·60	+0·7	8·2	− ·84
11	+ 4° 2560		20 39 55·6	·99	− ·15	+2·1	13·2	− ·48
July 8	+ 6° 2485		17 55 00·7	·98	− ·22	+1·3	12·6	− ·53
9	+ 1° 2701		18 23 01·0	·37	− ·93	+2·6	0·4	−1·00
9	+ 2° 2551		19 22 04·5	·71	+ ·70	−1·4	13·6	+ ·42
9	+ 1° 2709		19 23 51·8	1·00	− ·04	+0·8	13·9	− ·38
9	+ 2° 2552	1796	19 24 17·1	·71	+ ·71	+0·3	13·6	+ ·42
12	17 Libr	2137*	17 30 14·0	·99	+ ·17	+0·2	14·6	− ·12
12	18 Libr	2141*	18 02 50·4	·86	+ ·52	−0·6	14·3	+ ·25
13	203B. Libr	2279*	19 45 46·2	·47	+ ·88	−1·0	9·6	+ ·75
Aug. 6	− 0° 2648		17 54 40·3	·78	+ ·63	−1·0	14·2	+ ·33
7	− 4° 3563		16 43 14·4	·95	+ ·30	+0·3	14·9	− ·03
7	− 5° 3766		18 19 01·9	·78	+ ·62	+1·5	14·1	+ ·33
7	− 5° 3775		19 43 52·7	1·00	− ·02	+0·3	14·0	− ·35
8	− 9° 3977		17 20 25·6	·95	− ·31	+0·1	12·0	− ·58
10	ϕ Ophi	2372*	19 17 07·5	·72	+ ·69	−0·7	12·1	+ ·54
11	−18° 4586	2531*	22 45 18·6	·99	− ·17	+0·3	13·7	− ·26
Sept. 5	−12° 4232		18 14 06·1	·84	− ·55	+0·5	9·6	− ·75
6	−15° 4266	2325	18 33 34·3	1·00	− ·08	+0·9	13·8	− ·29
6	−15° 4269		19 06 11·9	·46	+ ·89	−2·0	9·2	+ ·77
6	−15° 4284		20 19 00·1	·65	+ ·76	−0·9	11·4	+ ·61
7	−17° 4718		18 00 40·5	·81	+ ·58	−0·3	12·6	+ ·46
7	−18° 4427		18 22 13·3	·94	+ ·33	+0·8	14·0	+ ·20
8	−19° 4832	2611*	16 32 01·3	·86	− ·50	+0·8	11·7	− ·56
8	39G. Sgtr	2629*	20 13 05·9	·65	− ·76	+0·4	8·6	− ·79
9	195B. Sgtr	2798*	18 10 26·5	·97	− ·25	+1·3	13·8	− ·21
Oct. 5	−19° 4725	2571*	18 04 02·5	·99	+ ·15	+0·9	14·1	+ ·07
7	57 Sgtr	2902*	18 16 25·0	·95	+ ·31	+0·7	13·0	+ ·40
Nov. 4	117° 6059	3022*	20 31 35·8	·95	+ ·32	−0·1	12·6	+ ·48

Date	Name or BD No.	NZC	U.T.	p	q	$\Delta\sigma$	Coeff. of $\Delta\alpha$	Coeff. of $\Delta\delta$
			h m s			″		
Nov. 5	42 Capr	3173*	21 51 11·0	·67	+ ·75	−0·7	6·7	+ ·89
6	58 Aqar	3310*	18 01 45·8	·62	+ ·79	0·0	5·3	+ ·93
6	−10° 5963	3324*	22 32 16·4	·81	+ ·58	−1·1	8·9	+ ·80
7	− 7° 6012	3449*	17 20 55·0	·93	+ ·38	−0·7	11·2	+ ·66
7	− 7° 6036	3463*	20 32 55·0	·63	− ·78	+0·3	12·7	− ·53
Dec. 4	− 7° 5975	3422*	20 28 46·3	·53	+ ·85	−0·3	3·3	+ ·97
1944								
Feb. 27	+ 6° 298		17 12 29·6	·95	+ ·30	−1·3	11·9	+ ·61
Mar. 2	372B. Taur	837*	19 46 15·0	·93	+ ·37	−1·3	12·4	+ ·47
29	+19° 863		17 51 11·9	1·00	− ·09	+0·6	14·1	+ ·06
29	+19° 865		17 54 58·5	1·00	− ·02	+0·5	14·0	+ ·13
30	+21° 1109		16 58 52·0	·90	+ ·43	−0·5	12·1	+ ·49
Apr. 28	+21° 1630	1143*	16 31 05·3	1·00	− ·09	−0·1	13·8	− ·16
28	+21° 1636		17 54 19·3	·57	− ·82	+1·3	7·1	− ·86
28	+21° 1640		18 11 51·2	1·00	+ ·07	−1·1	14·0	·00
29	+20° 2078		16 20 56·9	·96	+ ·27	−0·1	14·0	+ ·11
29	+20° 2079	1261*	16 21 40·5	·96	+ ·30	0·0	13·9	+ ·16
29	+20° 2084		17 55 27·4	·79	− ·61	+0·3	9·7	− ·72
30	+17° 2057		19 40 09·6	·55	− ·83	−0·5	5·1	− ·93
May 29	+13° 2281		19 13 29·1	·99	+ ·13	+0·4	14·4	− ·18
June 24	+17° 2092		16 38 36·1	·93	− ·38	−1·5	11·7	− ·58
25	+14° 2230		17 14 49·1	1·00	− ·03	+0·2	13·8	− ·32
26	+10° 2245		18 31 42·6	·98	− ·20	+1·5	12·7	− ·51
27	+ 6° 2518		19 16 09·2	·49	− ·87	+0·9	2·2	− ·99
July 1	ξ Libr	2133*	18 12 19·6	·94	− ·34	−1·1	11·5	− ·62
24	+ 8° 2521		16 21 06·6	·94	− ·35	−0·9	11·3	− ·65
24	+ 8° 2525		17 06 14·0	·84	+ ·55	+0·4	14·5	+ ·22
25	c Virg	1773*	17 20 58·5	·92	+ ·40	−1·2	15·0	+ ·04
26	− 0° 2655		17 33 03·8	1·00	+ ·09	+0·8	14·4	− ·28
27	− 4° 3563		17 07 28·0	·58	− ·81	+1·3	3·8	− ·97
27	− 5° 3766		18 29 24·2	·92	+ ·40	0·0	10·7	− ·70
27	− 4° 3577		18 36 23·6	·97	+ ·23	+0·3	14·8	− ·13
28	− 8° 3803		16 15 56·4	·98	− ·20	+2·4	12·7	− ·51
28	− 8° 3805		16 39 58·5	1·00	+ ·02	+2·8	14·1	− ·31
28	− 9° 3972		18 10 42·1	·89	+ ·46	−0·2	14·6	+ ·14
28	− 9° 3977		19 28 23·3	·92	+ ·38	+2·5	14·8	+ ·06
Aug. 1	μ Sgtr	2633*	17 46 03·4	·98	− ·18	−2·0	13·6	− ·24
22	+ 0° 2993		17 34 45·3	·85	+ ·53	−1·0	14·8	+ ·18
23	− 3° 3501		17 08 50·6	·94	− ·34	−0·5	11·3	− ·66
24	− 8° 3761	2057	17 35 49·5	·96	− ·27	−1·5	12·1	− ·58
26	−15° 4221	2280*	16 17 52·4	·72	− ·69	+0·7	7·5	− ·85
26	−15° 4228		17 58 17·0	·72	− ·70	+0·7	7·5	− ·86
28	−20° 4874	2556*	17 10 23·8	·77	− ·64	+0·8	9·8	− ·72
29	33 Sgtr	2746*	21 31 10·8	·99	− ·17	−1·6	13·8	− ·16
30	−21° 5522	2892*	17 04 03·5	·77	− ·64	+0·1	11·5	− ·57
Sept. 23	−17° 4601		17 15 44·2	·97	− ·23	−1·5	12·9	− ·43
23	−17° 4606	2390*	19 22 57·2	·86	+ ·50	−0·7	13·5	+ ·32
25	−21° 5012		19 04 07·2	·88	+ ·48	−0·8	12·5	+ ·45
25	−21° 5015		19 16 06·0	·87	+ ·49	−0·5	12·4	+ ·46
25	−21° 5013		19 19 17·4	·52	+ ·85	−1·4	7·8	+ ·83
25	−21° 5019		19 27 30·7	·93	+ ·36	+1·1	13·2	+ ·32
Oct. 23	−21° 5257		17 42 14·2	·86	+ ·51	−0·2	11·8	+ ·53
23	−21° 5261		17 57 47·7	·99	+ ·13	+0·9	13·8	+ ·15
23	−22° 4986		18 04 45·8	·97	− ·26	−1·7	13·5	− ·23
23	−21° 5273		19 03 35·0	+0·74	+ ·67	−1·0	+10·0	+ ·69

TABLE II

Adopted Positions of other than N.A. Stars

BD	R.A. (1939·0)	Red. to Date	Dec. (1939·0)	Red. to Date	Catalogue
	h m s	s	° ′ ″	″	
−18° 4871	18 12 21·34	+2·45	−18 15 42·8	+10·3	Yale 12
− 7° 5708	22 05 03·02	+2·88	− 6 40 54·0	+22·4	GC
	R.A. (1940·0)		Dec. (1940·0)		
+17° 656	3 52 00·03	+1·16	+17 27 28·3	− 4·7	Abbadia
+18° 783	5 05 40·55	+0·57	+18 52 59·5	− 8·5	,,
+16° 1589	7 53 17·54	+1·28	+16 17 14·9	−12·8	AG Berlin
+16° 1606	7 56 51·18	+1·29	+15 50 56·9	−13·0	Bordeaux 2nd
+18° 1348	6 43 48·85	+0·60	+18 23 20·9	−10·7	Abbadia
+14° 1929	8 32 50·93	+1·03	+13 59 10·4	−12·8	AG Leipzig
+14° 1930	8 32 53·17	+1·02	+13 58 40·7	−12·8	,,
	R.A. (1941·0)		Dec. (1941·0)		
+ 9° 271	2 03 30·94	−0·08	+10 11 48·9	− 6·0	NZC
+18° 839	5 20 03·04	+0·90	+18 32 47·3	− 9·4	Abbadia
+18° 777	5 01 23·52	+0·30	+18 10 24·7	− 9·6	,,
+18° 1027	5 53 19·90	+0·52	+18 56 01·2	−10·2	,,
+18° 1036	5 54 15·45	+0·53	+18 57 14·7	−10·3	Abbadia
+18° 1043	5 55 39·90	+0·53	+18 48 30·9	−10·3	,,
+18° 1046	5 56 03·52	+0·54	+18 50 56·7	−10·3	,,
+18° 1256	6 29 53·68	+0·25	+18 49 40·6	−10·7	,,
+18° 1258	6 30 04·67	+0·25	+18 37 28·5	−10·7	Bonn (Kü)
+15° 1807	8 18 54·11	+0·70	+15 39 00·9	−11·7	AG Berlin
+12° 2067	9 33 10·96	+0·40	+11 41 50·3	− 9·6	Wash. XIII
+ 8° 2368	10 26 10·08	+0·73	+ 8 12 48·2	− 9·1	AG Leipzig
+ 8° 2367	10 26 03·79	+0·73	+ 8 05 59·4	− 9·2	AN. 5853 (Eros)
+ 8° 2369	10 26 44·89	+0·73	+ 8 20 48·1	− 9·1	NZC
+ 8° 2370	10 27 02·07	+0·73	+ 8 12 00·3	− 9·1	Toulouse 3rd
+ 4° 2455	11 20 49·99	+1·03	+ 3 56 40·6	− 8·6	GC
+ 3° 2503	11 23 47·07	+1·05	+ 3 19 40·6	− 8·7	=83 Leon +^{s}·97, −24″·9
+ 0° 2914	12 11 58·79	+1·36	− 0 19 57·8	− 8·0	Bergedorf
+ 5° 2451	11 05 43·10	+0·73	+ 5 18 43·1	− 7·3	NZC
+ 5° 2452	11 05 54·21	+0·73	+ 5 22 25·0	− 7·3	AG Leipzig
+ 1° 2640	11 58 45·14	+1·00	+ 0 51 36·6	− 6·4	Abbadia
+ 1° 2641	11 59 19·93	+1·00	+ 0 53 31·8	− 6·4	,,
− 3° 3383	12 55 51·81	+1·34	− 3 36 51·6	− 5·1	,,
− 7° 3721	13 50 09·47	+1·71	− 7 48 24·5	− 3·6	AG Wien-Ott.
− 7° 3723	13 50 48·17	+1·72	− 8 11 35·8	− 3·7	GC
−11° 3814	14 47 23·86	+2·11	−11 46 29·1	− 1·4	GC
−11° 3822	14 50 05·08	+2·13	−11 59 22·9	− 1·3	Yale 11
− 6° 3850	13 34 08·27	+1·26	− 6 50 10·3	− 2·6	Abbadia
−13° 4183	15 28 16·15	+1·96	−14 07 00·2	+ 1·8	Yale 11
−13° 4188	15 29 21·76	+1·97	−14 16 22·6	+ 1·8	Yale 11
−13° 4193	15 30 46·05	+1·97	−14 01 56·2	+ 2·0	,,
−17° 4753	17 10 56·04	+2·05	−17 23 54·6	+ 7·9	Yale 12
−17° 4761	17 13 35·92	+2·07	−17 35 36·3	+ 8·0	,,
−17° 5381	18 52 27·50	+2·02	−17 39 27·5	+13·1	AG Wash.
−17° 5388	18 53 19·01	+2·03	−17 31 20·1	+13·2	Yale 12
−17° 5409	18 56 59·97	+2·03	−17 34 02·6	+13·4	NZC
−17° 5414	18 57 17·71	+2·04	−17 17 59·8	+13·5	Yale 12
−16° 5469	19 54 50·51	+2·27	−16 07 44·1	+16·1	,,
−14° 5861	20 46 40·45	+2·47	−13 51 46·0	+18·4	,,

BD	R.A. (1941·0)	Red. to Date	Dec. (1941·0)	Red. to Date	Catalogue
	h m s	s	° ′ ″	″	
−14° 5866	20 48 02·99	+2·48	−14 08 42·5	+18·3	NZC
−14° 5867	20 48 18·26	+2·48	−13 58 18·8	+18·4	Yale 12
−14° 5871	20 49 17·74	+2·48	−13 59 09·2	+18·5	,,
−13° 5790	20 52 07·96	+2·49	−13 29 24·2	+18·7	Yale 11
−13° 5793	20 52 33·00	+2·50	−13 39 04·0	+18·6	,,
−12° 6001	21 24 53·09	+2·22	−12 11 09·4	+18·1	Yale 11
−12° 6003	21 24 58·61	+2·22	+12 01 17·8	+18·2	,,
−12° 6002	21 24 56·08	+2·22	+12 20 47·5	+18·1	,,
− 6° 6088	22 50 33·92	+2·30	− 6 25 21·4	+17·7	Wash. XIII
− 6° 6096	22 52 17·51	+2·31	− 6 00 16·8	+17·8	Abbadia
	R.A. (1942·0)		Dec. (1942·0)		
+18° 1636	7 26 08·61	+0·23	+18 12 18·3	− 9·9	Wash. XIII
+19° 1650	7 09 50·74	−0·19	+19 01 14·9	− 9·2	Abbadia
+13° 2145	9 40 14·16	+0·49	+12 51 55·8	− 8·6	Bordeaux 2nd
+13° 2147	9 40 55·76	+0·50	+12 48 09·6	− 8·6	AG Leipzig
+16° 1789	8 36 24·00	−0·05	+16 20 51·6	− 7·9	Bordeaux 2nd
+14° 2097	9 24 45·39	+0·14	+14 00 09·1	− 7·3	Bordeaux 2nd
+13° 2098	9 26 43·34	+0·15	+13 37 06·7	− 7·4	Bonn (Kü)
+14° 2101	9 27 31·92	+0·15	+13 45 07·0	− 7·3	NZC
+ 7° 2413	11 03 51·60	+0·66	+ 7 00 43·6	− 6·5	Toulouse 3rd
+ 7° 2417	11 05 13·15	+0·67	+ 6 53 16·9	− 6·5	NZC
+ 7° 2421	11 07 11·08	+0·68	+ 6 37 15·5	− 6·5	Toulouse 3rd
− 0° 2595	12 35 58·14	+0·96	− 0 32 09·5	− 3·6	GC
− 3° 3461	13 21 25·34	+1·26	− 4 18 52·0	− 2·8	Abbadia
− 3° 3470	13 23 48·76	+1·27	− 4 19 11·9	− 2·6	,,
− 4° 3487	13 24 46·07	+1·28	− 4 40 05·2	− 2·7	,,
− 4° 3485	13 24 38·36	+1·28	− 4 49 05·5	− 2·8	Abbadia
− 8° 3750	14 15 51·53	+1·63	− 8 53 37·6	− 1·5	AG Wien-Ott.
− 2° 3651	13 10 21·66	+0·86	− 3 11 14·2	− 1·4	Wash. XIII
− 7° 3762	14 02 19·41	+1·17	− 7 43 11·2	− 0·3	,,
−10° 3992	14 55 00·63	+1·50	−11 06 04·3	+ 1·3	Yale 11
−10° 3993	14 55 05·10	+1·50	−11 06 52·3	+ 1·3	Yale 11
−11° 3854	14 57 22·06	+1·52	−11 38 42·5	+ 1·3	,,
−11° 3862	14 59 09·53	+1·53	−11 30 49·8	+ 1·4	,,
−14° 4311	15 52 25·05	+1·88	−14 51 40·2	+ 3·2	Yale 12
−16° 4325	16 36 28·69	+1·66	−16 30 00·1	+ 5·8	,,
−16° 4327	16 38 13·67	+1·67	−16 49 22·1	+ 5·8	Yale 12
−17° 4793	17 20 02·36	+1·41	−17 55 02·5	+ 7·9	,,
−17° 4797	17 20 55·46	+1·42	−18 04 50·8	+ 7·9	,,
−18° 4524	17 21 57·05	+1·42	−18 13 49·8	+ 7·8	,,
−18° 4952	18 21 19·18	+1·69	−18 46 07·7	+10·2	,,
−18° 4950	18 21 16·37	+1·68	−18 39 45·9	+10·2	Hyderabad Ast.
−18° 4953	18 21 35·66	+1·68	−18 34 17·3	+10·3	Yale 12
−18° 4960	18 22 47·46	+1·69	−18 34 25·2	+10·3	,,
−18° 4965	18 23 33·30	+1·69	−18 39 02·4	+10·3	,,
−18° 4967	18 23 37·00	+1·69	−18 31 43·8	+10·4	,,
−19° 5007	18 23 47·16	+1·70	−18 59 22·4	+10·2	Yale 12
−18° 4976	18 25 23·26	+1·70	−18 32 43·6	+10·4	,,
−18° 5373	19 24 17·69	+1·96	+18 28 07·6	+12·7	GC
−18° 4789	18 03 17·79	+1·26	−18 59 28·8	+ 9·3	NZC
−17° 5901	20 09 56·91	+1·70	−17 03 18·2	+13·5	Yale 12

BD	R.A. (1942·0)	Red. to Date	Dec. (1942·0)	Red. to Date	Catalogue
	h m s	s	° ′ ″	″	
−17° 5913	20 11 55·38	+1·71	−17 01 41·7	+13·6	NZC
−14° 5949	21 06 51·93	+1·93	−14 30 21·2	+15·3	Yale 12
−15° 5911	21 08 53·89	+1·94	−14 47 48·9	+15·2	,,
−14° 5960	21 09 34·46	+1·95	−14 37 53·3	+15·3	,,
−14° 5956	21 08 46·40	+1·94	−14 17 07·6	+15·4	,,
− 7° 5911	22 58 44·99	+2·46	− 7 16 20·1	+17·6	Abbadia
− 9° 6039	22 40 24·20	+2·02	− 8 43 22·0	+15·4	GC
− 9° 6054	22 43 18·42	+2·04	− 8 41 43·1	+15·3	Abbadia
− 8° 5945	22 44 03·16	+2·04	− 8 28 21·8	+15·4	,,
− 8° 5952	22 45 20·61	+2·05	− 8 25 08·8	+15·4	NZC
	R.A. (1943·0)		Dec. (1943·0)		
+ 2° 149	1 00 29·52	−0·52	+ 2 56 59·2	− 6·8	Abbadia
+ 0° 106	0 39 06·69	−0·97	+ 0 42 42·8	− 8·5	Yale 5
+ 0° 107	0 39 11·35	−0·97	+ 0 45 04·9	− 8·5	,,
+17° 751	4 31 24·12	−0·24	+17 37 51·8	− 8·5	NZC
+19° 1308	6 17 39·21	+0·26	+19 57 09·0	− 8·2	Abbadia
+18° 783	5 05 51·11	−0·56	+18 53 13·1	− 8·7	,,
+20° 1596	6 48 19·53	−0·12	+20 01 00·1	− 7·7	Yale 10
+20° 1454	6 27 17·39	−0·60	+20 27 40·6	− 7·5	,,
+18° 1869	8 09 15·21	−0·16	+18 41 20·2	− 6·5	Wash. XIII
+14° 2157	9 47 45·02	+0·36	+14 23 13·8	− 5·9	Bordeaux 2nd
+19° 1869	7 51 34·97	−0·50	+19 23 37·8	− 5·9	GC
+19° 1872	7 52 32·33	−0·49	+19 31 03·6	− 5·8	Abbadia
+18° 2037	8 43 16·14	−0·29	+17 42 19·6	− 5·1	Wash. XIII
+15° 2075	9 32 25·35	−0·06	+15 04 49·8	− 4·6	Bordeaux 2nd
+ 9° 2465	11 08 24·94	+0·49	+ 8 34 37·1	− 4·1	AG Leipzig
+ 4° 2549	11 53 34·74	+0·78	+ 4 22 52·1	− 4·2	AN. 5141 (Wilh.)
+ 4° 2560	11 58 15·02	+0·80	+ 3 56 59·1	− 4·2	GC
+ 6° 2485	11 39 31·66	+0·40	+ 5 49 17·8	− 2·4	Toulouse 3rd
+ 1° 2701	12 25 59·51	+0·69	+ 1 27 53·3	− 2·2	GC
+ 2° 2551	12 28 16·57	+0·70	+ 1 38 46·5	− 2·1	GC
+ 1° 2709	12 28 20·41	+0·70	+ 1 26 21·8	− 2·2	Abbadia
+ 2° 2552	12 28 19·74	+0·70	+ 1 38 30·9	− 2·1	NZC
− 0° 2648	13 00 01·43	+0·60	− 1 12 07·6	− 0·4	Abbadia
− 4° 3563	13 46 18·43	+0·88	− 5 20 51·6	+ 0·1	AG Strass.
− 5° 3766	13 48 23·40	+0·89	− 5 30 42·5	+ 0·1	Abbadia
− 5° 3775	13 50 38·83	+0·91	− 5 54 24·1	0·0	Pulk. LVI
− 9° 3977	14 36 41·67	+1·20	− 9 42 18·5	+ 0·6	Wash. XIII
−12° 4232	15 15 16·34	+1·03	−12 43 02·8	+ 2·4	Yale 11
−15° 4266	16 09 35·85	+1·34	−15 52 19·6	+ 3·6	NZC
−15° 4269	16 10 10·70	+1·34	−15 37 45·6	+ 3·7	Yale 12
−15° 4284	16 12 39·15	+1·36	−15 44 44·6	+ 3·8	,,
−17° 4718	17 05 07·52	+1·67	−18 05 48·9	+ 5·3	,,
−18° 4427	17 05 47·85	+1·67	−18 11 02·9	+ 5·3	,,
	R.A. (1944·0)		Dec. (1944·0)		
+ 6° 298	1 51 33·70	−1·10	+ 6 47 18·8	− 9·9	AG Leipzig
+19° 863	5 08 37·91	−0·67	+19 51 48·6	− 6·3	Abbadia
+19° 865	5 08 43·59	−0·67	+19 53 03·7	− 6·3	,,
+21° 1109	6 01 55·85	−0·42	+21 23 31·4	− 5·2	Yale 10

BD	R.A. (1944·0)	Red. to Date	Dec. (1944·0)	Red. to Date	Catalogue
	h m s	s	° ′ ″	″	
+21° 1636	7 30 41·50	−0·45	+21 14 45·3	− 3·6	Yale 10
+21° 1640	7 31 40·28	−0·45	+21 26 19·5	− 3·6	,,
+20° 2078	8 21 34·13	−0·19	+20 19 30·7	− 3·1	,,
+20° 2084	8 23 13·94	−0·18	+19 57 50·2	− 3·2	,,
+17° 2057	9 15 29·18	+0·11	+17 28 29·6	− 3·4	Bordeaux 2nd
+13° 2281	10 34 36·21	+0·20	+12 38 40·9	− 2·1	AN. 5853 (Eros)
+17° 2092	9 25 56·03	−0·42	+17 21 41·2	− 0·9	Bordeaux 2nd
+14° 2230	10 15 25·72	−0·18	+14 12 51·8	− 0·6	,,
+10° 2245	11 03 42·15	+0·08	+10 15 40·9	− 0·7	,,
+ 6° 2518	11 49 17·54	+0·36	+ 5 56 16·8	− 1·1	Wash. XIII
+ 8° 2521	11 31 12·01	+0·01	+ 7 51 52·7	+ 0·4	Toulouse 3rd
+ 8° 2525	11 32 23·99	+0·01	+ 7 56 09·1	+ 0·4	AG Leipzig
− 0° 2655	13 02 18·57	+0·51	− 0 51 55·3	− 0·1	Yale 5
− 4° 3563	13 46 21·56	+0·78	− 5 21 09·5	− 0·4	AG Strass.
− 5° 3766	13 48 26·53	+0·79	− 5 31 00·3	− 0·4	Abbadia
− 4° 3577	13 48 52·40	+0·80	− 5 23 31·7	− 0·3	Abbadia
− 8° 3803	14 32 46·25	+1·08	− 9 21 05·0	− 0·4	,,
− 8° 3805	14 33 18·28	+1·08	− 9 22 08·0	− 0·4	,,
− 9° 3972	14 35 04·15	+1·09	− 9 29 47·5	− 0·4	,,
− 9° 3977	14 36 44·95	+1·10	− 9 42 34·6	− 0·4	,,
+ 0° 2993	12 48 59·66	+0·17	+ 0 23 23·6	+ 1·1	Yale 5
− 3° 3501	13 32 37·75	+0·37	− 4 06 15·5	+ 0·9	Abbadia
− 8° 3761	14 18 48·23	+0·62	− 8 25 03·2	+ 0·7	NZC
−15° 4228	15 56 02·75	+1·20	−16 03 47·3	+ 1·1	Yale 12
−17° 4601	16 31 37·23	+0·94	−18 11 17·1	+ 2·2	,,
−21° 5012	18 24 46·27	+1·56	−20 23 08·4	+ 4·7	Yale 13
−21° 5015	18 25 06·19	+1·56	−21 22 30·3	+ 4·7	,,
−21° 5013	18 24 48·97	+1·56	−21 16 29·7	+ 4·8	,,
−21° 5019	18 25 30·07	+1·56	−21 24 14·4	+ 4·8	AG Algiers
−21° 5257	19 04 04·41	+1·26	−21 42 09·3	+ 5·4	Yale 13
−21° 5261	19 04 40·18	+1·26	−21 47 04·3	+ 5·4	Yale 13
−22° 4986	19 04 50·81	+1·27	−21 52 41·2	+ 5·3	Cordoba 2nd GC
−21° 5273	19 06 19·90	+1·27	−21 33 18·5	+ 5·5	Yale 13

Radcliffe Observatory,
Pretoria:
1945 *March* 16.

OCCULTATIONS OF STARS AND PLANET BY THE MOON, OBSERVED AT THE NIZAMIAH OBSERVATORY, HYDERABAD, DURING THE YEAR 1944

(Communicated by the Director)

(Received 1945 April 23)

TABLE I

No.	Star	Mag.	Phase	Date 1944	U.T. h m s
1	*m* Tauri	5·0	D	Jan. 7	20 24 37·1
2	BD +19° 1110	6·0	D	,, 8	14 01 42·2
3	χ^1 Orionis	4·6	D	,, 8	15 36 03·2
4	χ^2 Orionis	4·7	D	,, 8	22 11 06·2
5	34 Leonis *m*	6·4	R	,, 13	18 28 09·8
6	ξ Libræ	5·6	R	,, 19	22 25 26·7
7	BD +1° 223	6·8	D	,, 30	13 10 17·2
8	56 Geminorum	5·2	D	Feb. 6	13 03 44·4
9	61 Geminorum	5·9	D	,, 6	16 50 01·9
10	BD +9° 353	6·7	D	,, 28	14 47 19·2
11	BD +17° 731	7·3	D	Mar. 1	14 32 47·4
12	115 B. Sagittarii	5·8	R	Apr. 14	20 30 23·5
13	BD +18° 2129	7·4	D	,, 30	13 41 53·9
14	BD −9° 3945	6·7	D	June 3	21 14 45·5
15	49 Libræ	5·5	D	,, 5	13 38 22·7
16	BD −18° 4320	6·9	D	Aug. 27	14 57 33·9
17	139 B. Cancri	6·1	R	Oct. 10	21 43 12·1
18	BD +22° 1416	6·3	D	Nov. 4	18 07 24·7
19	BD +22° 1416	6·3	R	,, 4	19 15 19·6
20	Saturn	0·0	D	,, 5	0 46 18·0
21	39 Cancri	6·5	D	Dec. 31	17 48 13·0
22	40 Cancri	6·5	D	,, 31	17 56 30·8

The first fifteen observations were made by M. K. Bappu and the rest by M. V. V. Sastry. The instrument used throughout was the 15-inch visual refractor. The corrections to the standard clock were determined from observations with the transit instrument.

The reductions were carried out by M. V. V. Sastry, assisted by S. Aravamudan. No correction was added to the observed time. Nos. 21 and 22 were observed at the bright limb.

TABLE II

No.	$\sigma' - \sigma$	$\cos(\rho - \chi)$	$\sin(\rho - \chi)$	No.	$\sigma' - \sigma$	$\cos(\rho - \chi)$	$\sin(\rho - \chi)$
	″				″		
1	+1·8	+0·55	−0·83	12	−0·6	−0·90	+0·45
2	−0·2	+0·93	−0·37	13	+0·9	+0·99	−0·16
3	−0·1	+0·74	+0·67	14	−1·2	+0·96	−0·27
4	+0·9	+0·96	−0·29	15	+0·5	+0·71	−0·71
5	+1·2	−0·99	−0·17	16	−1·9	+0·96	+0·29
6	+0·9	−0·93	+0·36	17	+0·4	−0·50	−0·87
7	+0·3	+0·33	+0·94	18	+0·8	+0·85	+0·52
8	+0·1	+0·93	+0·37	19	+0·6	−0·98	+0·20
9	−0·1	+0·82	−0·57	20	−1·3	+0·97	+0·23
10	+0·8	+0·66	+0·75	21	[+4·1]	+0·88	−0·48
11	−0·3	+0·69	+0·72	22	[+4·2]	+0·78	−0·62

The mean place for 1944·0 of star No. 11 in the list is given below. Proper motions have been applied to the co-ordinates given in the catalogue in computing the mean place for use in the reduction.

No.	R.A. (1944·0)	Dec. (1944·0)	Remarks
11	$4^h\ 26^m\ 06^s{\cdot}08$	$+17°\ 25'\ 24''{\cdot}0$	AG Berlin 1193; $\mu_a = +0^s{\cdot}39$; $\mu_\delta = -2''{\cdot}4$.

Nizamiah Observatory,
Hyderabad, Deccan, India :
1945 *April.*